J. Physiol. (1982), **331**, *pp.* 461–467
With 3 *text-figures*
Printed in Great Britain

EFFECTS OF MEAL TEMPERATURE AND VOLUME ON THE EMPTYING OF LIQUID FROM THE HUMAN STOMACH

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(*Received 16 March 1982*)

SUMMARY

1. The effects of meal temperature and volume on the emptying of liquid meals have been studied in eight normal volunteers. Four drinks were investigated: (i) 200 ml, 12 °C, (ii) 200 ml, 37 °C, (iii) 500 ml, 12 °C, (iv) 500 ml, 37 °C. Gastric emptying was measured by real-time ultrasound.

2. After an initial rapid phase of emptying, measured by the volume retained in the stomach at 5 min, emptying was mono-exponential and measured as a half-life.

3. The 5 min gastric volume was significantly reduced by giving a cold drink of 500 ml (12 °C: 250 ± 33·1 ml, 37 °C: 307 ± 25·8 ml, $P < 0{\cdot}05$). Temperature had no significant effect on the subsequent half-life of emptying.

4. The half-life was longer for meals of larger volume; at 37 °C this was statistically significant: 200 ml: $t_{\frac{1}{2}}$ 7·6 ± 2·1 min; 500 ml: $t_{\frac{1}{2}}$ 15·3 ± 2·8 min; $P < 0{\cdot}01$.

5. There was a significant positive correlation between the 5 min volume and the subsequent half-life of emptying for all meals except 200 ml at 12 °C, suggesting that resting gastric muscle tone affects both phases of gastric emptying.

6. Significant correlations within subjects for 5 min volume measurements for meals of different volume and temperature and half-lives of meals at 37 °C suggests that individuals have their own characteristics of gastric emptying for liquid meals.

INTRODUCTION

The physiology of gastric emptying remains an area that is relatively difficult to study non-invasively in man. The emptying of liquid from the stomach has been studied principally by the serial test meal (Hunt & Spurrell, 1951). Using this technique Hunt & MacDonald (1954) investigated the emptying of liquid meals of 350, 750 and 1250 ml. More recently Erskine & Hunt (1981) have investigated the emptying of small volume liquid meals. The emptying of liquid from the stomach can be divided into at least two phases, an initial rapid phase followed by a slower mono-exponential decline. Hunt & MacDonald found that this secondary phase of emptying was slower with meals of larger volume. Erskine & Hunt reported that with the small volume meals they investigated gastric emptying was independent of the volume used, and was rapid.

The series of experiments described here were designed to investigate the effects of temperature and volume on the emptying of liquid meals in a group of normal volunteer subjects. The technique which has been used for these studies has been recently developed and is based on real-time ultrasound (Bateman & Whittingham, 1982).

METHODS

Eight normal male volunteer subjects aged 21–29 years participated in the experiments. They attended the laboratory at 9–10 a.m. after an overnight fast, and were seated in an upright chair for 5 min before each meal and throughout the emptying period. Four separate liquid meals of orange cordial (Co-operative Wholesale Society, Whole Orange Drink) were used for the experiments, the concentrate being diluted with tap water in a proportion of four parts water to one part cordial giving a final pH of 3·5 and an osmolality of 680 mosmol/kg, dextrose content of 20 g/l and fructose 24·8 g/l. The meals consumed were as follows: (i) 200 ml at 12 °C, (ii) 200 ml at 37 °C, (iii) 500 ml at 12 °C, (iv) 500 ml at 37 °C. The order in which the meals were consumed was randomized. The drink was consumed at a speed which was as rapid as the subjects could comfortably manage (mean 11 s for 200 ml and 38 s for 500 ml).

Gastric volume was measured by real-time ultrasound, (Bateman & Whittingham, 1982) before each drink and at 5, 10, 15, 20, 25, 30, 40, 50 and 60 min after the drink. The average of two measurements at each time point was used in the calculation of gastric volume. The method is based on the fact that the stomach is transonic when containing liquid and thus its walls can be clearly outlined by a real-time ultrasound scanner. The volume calculation is performed by measuring the area of regularly spaced (1 cm) cross-sections of the stomach which are taken at right angles to its long axis. To obtain the series of scans for each volume measurement the subject holds his breath in inspiration and the scanning probe (9 cm in length) is swept along the long axis of the stomach at right angles to it. The scans are recorded on video tape, and the position of the probe on the abdomen is obtained by constraining it within a gantry mechanism. The series of scans are subsequently replayed and the area of each slice measured by a microcomputer. *In vitro* measurements have shown that this is an extremely accurate and reproducible method with a root mean square error of 4 %.

Gastric volume, from 5 min after the ingestion of the meal until the subject's stomach has emptied to less than 20 ml declines mono-exponentially (Fig. 1). Back extrapolation of the log gastric volume–time plot to zero invariably results in a volume which is significantly less than the meal volume. This early, rapid phase of emptying is reflected by the '5 min volume'. The subsequent rate of emptying is expressed as a half-life, and is calculated by least squares regression analysis. Statistical analysis was performed using the Wilcoxon's signed rank test, and correlations calculated from Spearman's co-efficient (r_s).

RESULTS

(i) 5 min volume

The volume of liquid in the stomach 5 min after the 200 ml drinks (Table 1) was unaffected by temperature ($87 \pm 16·4$ ml at 12 °C; $98 \pm 16·2$ ml at 37 °C). Thus on average more than 50 % of the meal (12 °C; 56 %; 37 °C; 51 %) had left the stomach by 5 min. After the 500 ml drink the volume in the stomach was significantly less than the colder meal ($250 \pm 33·1$ ml at 12 °C, $307 \pm 25·8$ ml at 37 °C, $P < 0·05$). The proportion of the larger meals that had left the stomach within 5 min was less than for the 200 ml meals (12 °C: 50 % and 37 °C: 38 %). The 5 min volume measurements within subjects were significantly correlated for meals of different temperature and volume except for the relation between 12 °C meals of 200 and 500 ml (Table 2, Fig. 2*A*).

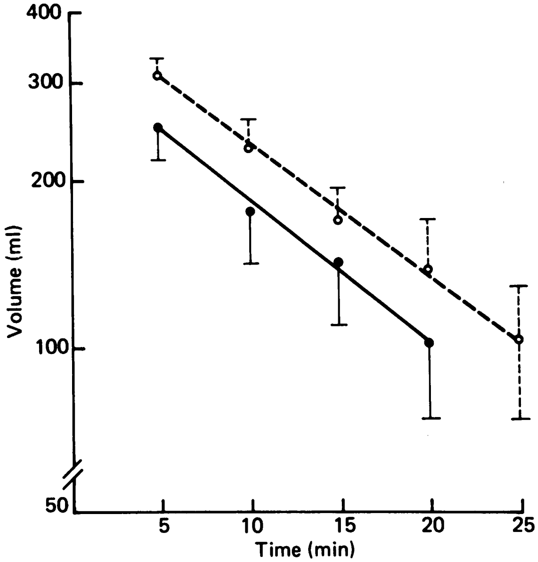

Fig. 1. Emptying of 500 ml meals at 12 °C (●——●) and 37 °C (○----○) Mean ± S.E. of mean are shown.

TABLE 1. 5 min volume (ml) measurements and half-life (min) for meals of different temperature and volume

Volume...	200 ml				500 ml			
Temperature...	12 °C		37 °C		12 °C		37 °C	
Subject	5 min volume	$t_{\frac{1}{2}}$	5 min volume	$t_{\frac{1}{2}}$	5 min volume	$t_{\frac{1}{2}}$	5 min volume	$t_{\frac{1}{2}}$
1	167	17·3	136	18	376	28	428	24·8
2	91	6·4	108	4·6	320	26·9	320	16·8
3	138	9	184	15·4	367	17·7	394	22·1
4	100	12·0	97	6·1	166	11·0	289	11·0
5	45	11·0	86	3·5	133	3·8	228	11·8
6	46	9·6	56	2·7	242	10·1	278	6·7
7	41	5·2	44	3·3	184	11·7	220	4·7
8	68	2·7	69	7·1	209	9·8	300	24·9
Mean	87	9·1	98	7·6**	250*	14·8	307*	15·3**
± S.E. of Mean	16·4	1·6	16·2	2·1	33·1	3·0	25·8	2·8

$^*P < 0{\cdot}05$; $^{**}P < 0{\cdot}01$.

TABLE 2. Spearman rank correlations for 5 min volumes within subjects

Meals	r_s	P
12 °C, 200 ml : 37 °C, 200 ml	0·881	< 0·01
12 °C, 500 ml : 37 °C, 500 ml	0·833	< 0·05
12 °C, 200 ml : 12 °C, 500 ml	0·690	n.s.
37 °C, 200 ml : 37 °C, 500 ml	0·867	< 0·01

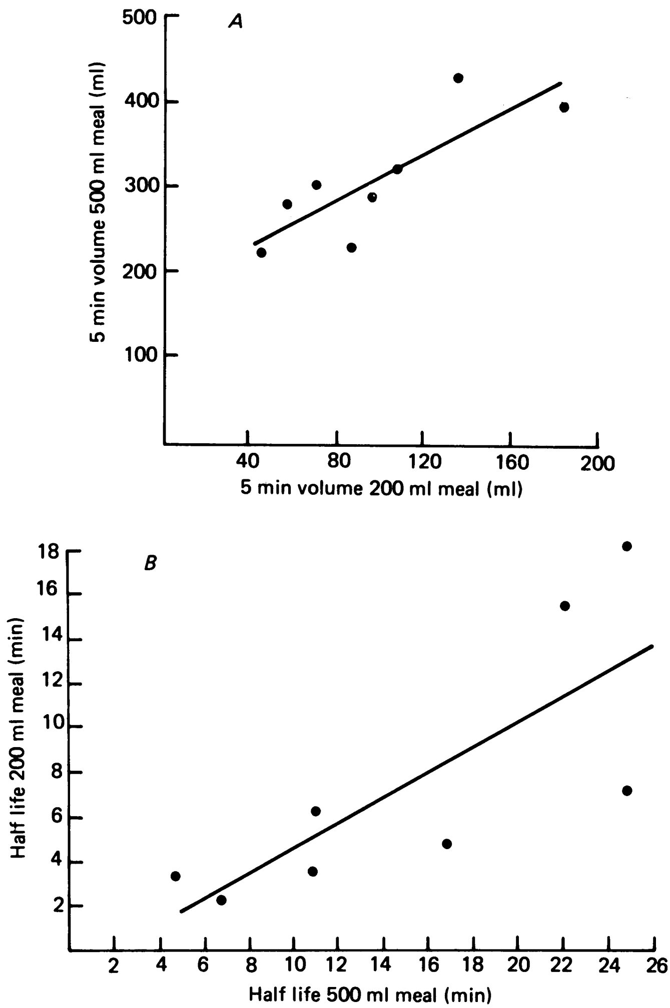

Fig. 2.*A*, relationship between 5 min volumes for meals at 37 °C. The line plotted is the least squares linear regression line $y = 1{\cdot}32x + 178$. $r_s = 0{\cdot}867$, $P < 0{\cdot}01$. *B*, relationship between half-lives of emptying for meals at 37 °C. The line plotted is the least squares linear regression $y = 0{\cdot}56x - 102$. $r_s = 0{\cdot}833$, $P < 0{\cdot}05$.

(*ii*) *Half-life of emptying*

The half-life of emptying of liquid from the stomach was longer with meals of larger volumes, although this was only statistically significant for meals at 37 °C (mean 200 ml: $t_{\frac{1}{2}} = 7{\cdot}6 \pm 2{\cdot}1$ min, 500 ml: $t_{\frac{1}{2}} = 15{\cdot}3 \pm 2{\cdot}8$ min, $P < 0{\cdot}01$, Table 1). There was a significant within subject correlation for the half-life of emptying of 200 and 500 ml drinks at 37 °C (Fig 2*B*)

(*iii*) *Relation between 5 min volume and emptying half-life*

There was a significant positive correlation between the 5 min volume in the stomach and the subsequent half-life for all the meals except those of 200 ml at

12 °C. The Spearman rank correlations were as follows: 12 °C, 500 ml meal: r_s 0·876, $P < 0·01$; 37 °C, 200 ml meal: r_s 0·786, $P < 0·05$; 37 °C, 500 ml meal: r_s 0·786, $P < 0·05$. The relation for the 500 ml meal at 37 °C is shown in Fig. 3.

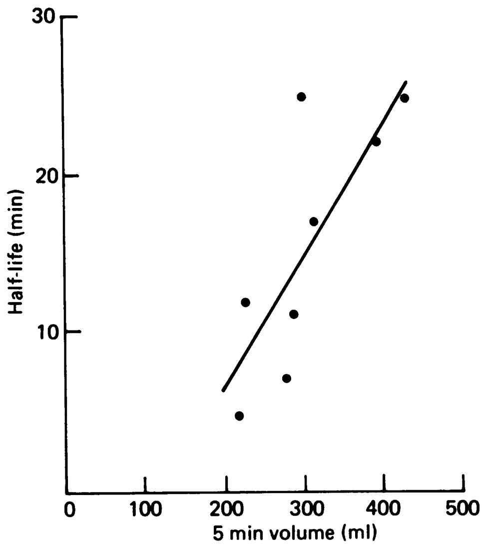

Fig. 3. Relationship between 5 min volume measurement and subsequent half-life of emptying for 500 ml meals at 37 °C. The line plotted is the least squares linear regression line $y = 0·086x - 11·1$. $r_s = 0·786$, $P < 0·05$.

DISCUSSION

Gastric emptying has been studied by a variety of techniques. Each of these has potential disadvantages (Sheiner, 1975). Ultrasound is non-invasive and does not cause discomfort to the subjects; its other advantage is that frequent volume measurements can be obtained during the emptying of a single meal. No correction, however, is made for gastric secretion during the emptying of the meal, since the total volume of liquid within the stomach is measured. The first volume measurement is taken at 5 min because air-bubbles in the liquid meal make clear visualization of the posterior stomach wall difficult before this time. Ultrasound is unsuitable for examining the emptying of solids since these reflect the sound beam, but for liquid meals offers a safe non-invasive method for investigating the physiology of gastric emptying under a variety of conditions.

In the classical work of Hunt (Hunt & McDonald, 1954) it was found that the initial rate of emptying of liquid from the stomach varied between individuals, and Hunt described this in terms of the 'starting index' (the time at which the back-extrapolated log–linear emptying curve was equivalent to the meal volume). This 'starting index' thus reflects both the slope of the emptying curve and the volume in the stomach at the time points studied. The meal that was used in the current studies produced 'zero' time volumes that were significantly less than the original meal volume. Thus for the orange drink used in these experiments there was an initial rapid phase of emptying followed by a slower mono-exponential decline. Instead of a 'starting index' the 5 min volume has been used as an indicator of the initial phase of emptying as this is independent of the slope of the subsequent emptying curve. It seems likely that the 5 min volume is directly related to the gastric adaptation response to the liquid drink because it is possible to visualize with ultrasound the liquid running out of the pylorus as a meal is drunk.

The 5 min volume showed a wide inter-individual variation, and this variation is similar to that reported for the 'starting index' by Hunt (Hunt & McDonald, 1954). The rate of emptying of the stomach also varied widely (Table 1). The results were, however, consistent within subjects and both the 5 min volume measurements for meals of different temperature and volume and the emptying half-lives for meals at 37 °C were significantly correlated (Fig. 2*A*, *B*, Table 2). These results suggest that the pattern of emptying of liquid from the stomach is a characteristic which varies between individuals but is, at least over the short time period during which these experiments were conducted, reproducible for each subject. This conclusion is supported by Erskine & Hunt (1981) who reported that within individuals the gastric response to a trisodium citrate meal predicted the response to a glucose meal.

The effect of meal volume on stomach emptying was studied by Hunt & Macdonald (1954). The meals used were 350, 750 and 1250 ml, and it was found that the emptying was more rapid for the smaller meals. In the current experiments proportionally more of a smaller meal had left the stomach within 5 min (Table 1) and there was a significantly shorter half-life of emptying for the 200 ml meal at 37 °C ($7{\cdot}6 \pm 2{\cdot}1$ min) than the 500 ml meal ($15{\cdot}3 \pm 2{\cdot}8$ min). Erskine & Hunt (1981) examined the emptying of small meal volumes, (25–200 ml); they measured the volume at 3 or 10 min after trisodium citrate or glucose meals respectively, and in the majority more than 50% of the volume had emptied. These findings suggest that for smaller volume drinks of various compositions emptying in the initial phase is rapid. The scatter in the results for both 5 min volume and half-life measurements (Table 1) suggests that factors in the individual may be as important in governing the response of the stomach to a liquid meal as the composition of the meal itself.

Temperature effects on gastric emptying have not been extensively investigated in man. Ritschel & Erni (1977) using a pH-sensitive capsule as an indicator of gastric emptying found that the capsule entered the small bowel much more rapidly with a cold drink than with a warm one. These findings can be related to the ones reported here. Thus, for 500 ml meals the 5 min gastric volume measurements were significantly less with the 12 °C meal than the 37 °C meal, the respective mean volume measurements being $250 \pm 33{\cdot}1$ ml and $307 \pm 25{\cdot}8$ ml ($P < 0{\cdot}05$). The subsequent rates of gastric emptying from the 5 min time point were not dependent on the meal temperature and it is quite conceivable that the cold liquid in the stomach would have been warmed to body temperature over the initial phase of the meal. These experiments suggest, however, that meal temperature affects adaptive relaxation mechanisms. Warm liquid resulted in greater relaxation of gastric muscle as indicated by the reduction in the initial emptying, and the subsequent higher 5 min gastric volume. It may therefore be that there is a physiological explanation for the common observation that warm drinks are more 'filling' than cold ones. It might be of interest to investigate patients with dumping syndrome to establish whether the temperature of the drink affects their symptoms. Finally, it is perhaps more logical to take oral medications, which are principally absorbed in the small bowel, with a cold liquid drink.

Since the 5 min gastric volume was significantly correlated with the subsequent rate of emptying it appears that the two phases of emptying are related, the more rapid the initial phase of emptying, the shorter the subsequent half-life. The initial phase of emptying seems likely to be a function of gastric adaptive relaxation and hence gastric muscle tone. Thus the tone in the stomach wall may influence the subsequent pattern of gastric emptying.

This work is supported by a grant from the Wellcome Trust. The author gratefully acknowledges the advice and encouragement of Professor M. D. Rawlins.

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